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Langley Research Center



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Ion Implantation Reduces Radiation Sensitivity of Metal-Oxide-Silicon (MOS) Devices

The problem:

In MOS devices, ionizing radiation produces two effects on thermally grown silicon oxide on silicon: (1) a net positive space charge is created in the oxide; and (2) fast surface states are introduced at the oxide/silicon interface. Both of these effects can produce structural instabilities in metal-oxide-silicon devices, and can cause circuits that are operating satisfactorily to drift and malfunction.

The solution:

The implantation of N_2^+ ions hardens the silicon oxide against the effects of ionizing radiation.

How it's done:

Two changes in silicon oxide contribute to radiation hardening: (1) the introduction of impurities to perturb electronic levels, altering carrier kinetics; and (2) the formation of structural imperfections. Both of these are accomplished by the technique of ion implantation. The properties of a standard, thermally grown silicon oxide are modified, reducing the sensitivity to ionizing radiation, yet preserving the stability normally shown by interfaces between silicon and thermally grown oxides.

For implantation, an ion source was used to generate a nitrogen ion plasma. Ions were extracted from this plasma and then accelerated down a 61 to 91 cm (2 to 3 ft) column by a 6.4×10^{14} J (400 keV) Van de Graaff accelerator. A beam of N_2^+ ions was then isolated by an analyzing magnet capable of sorting ions into species of specific mass-to-charge ratios. A quad magnet was used to spread the beam, improving the beam pattern uniformity ($\pm 30\%$ of nominal). Successful implantations were

carried out with 8.10×10^{15} J (50 keV) N_2^+ particles at a flux rate of $10^{16}/cm^2$.

The target chamber was evacuated to about 1.33 MN/m^2 (10^5 torr) by an oil-free turbomolecular pump. The temperature of the targets was held within a range of about 283 to 288 K above room temperature. The targets themselves were standard, thermally grown silicon oxide, 2000 Å thick, on silicon.

The chief source of irradiation throughout the experiment was a Brad-Thompson electron gun. Electron energies varied from 6.4×10^{16} to 3.2×10^{15} J (4 to 20 KeV), with 3.2×10^{15} J being used for most of the irradiations, and the flux varying from 10^{12} to 10^{17} particles/ cm^2 .

The primary property measured in analyzing the oxides and modified oxides was the capacitance-voltage property of a metal-oxide-silicon structure. While the method is extremely powerful for understanding the properties of the oxide-silicon interface, the only quantitative value recorded during these experiments was that of the flat-band voltage. This is the voltage, applied to the metal electrode, at which the MOS capacitor has the capacitance value corresponding to zero potential applied to the ideal capacitor. (The ideal capacitor is a capacitor in which all voltages applied to the metal electrode are balanced by charges in the silicon surface space-charge region). Consequently, the flat-band voltage is a measure of departure from the ideal capacitance.

In these experiments, it was assumed that the change in the flat-band voltage value was an effect caused by charges introduced during irradiation.

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These charges could either be in the form of an oxide space-charge or an interface state at the oxide/silicon interface. The flat-band value does not distinguish between these two charge sources.

The experiments showed that the radiation hardness of thermal oxides improved 30% to 60% as a result of N_2^+ ion implantation. This approach to radiation hardening retains all the advantages of the well-established and highly perfected techniques of thermal oxidation, and requires the degradation of only one specific property: the electron lifetime in the oxide. Most of the work of this investigation was carried out on implantations which were sufficiently high in fluence to introduce a small shift in the initial capacitance-voltage characteristic of the MOS device used for evaluating the modification. The magnitude of this shift is small compared to the improvement in radiation hardness, but does vary with fluence. The optimum ion, fluence, and range (energy) have not yet been identified.

Note:

The following documentation may be obtained from:

National Technical Information Service
Springfield, Virginia 22151
Single document price \$3.00
(or microfiche \$0.95)

Reference:

NASA-CR-1584 (N70-26555), The Development of Radiation Resistant Insulating Layers for Planar Silicon Technology.

Patent status:

No patent action is contemplated by NASA.

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